FREE SURFACE DEFORMATION BY THE APPLICATION OF ELECTRICAL CURRENTS

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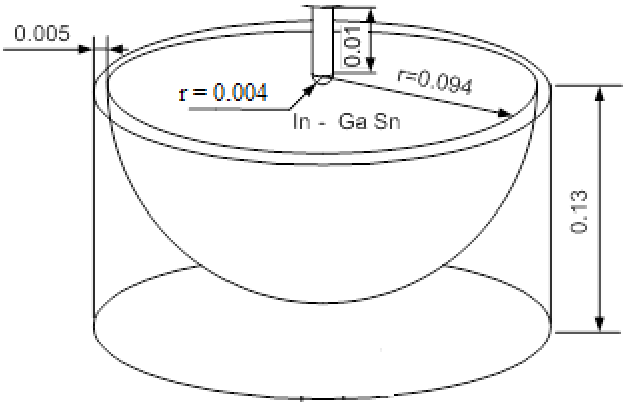
Abstract: We report some results from an investigation on an electrically induced flow in a cylindrical container filled with an In-Ga-Sn alloy. An electric current is applied from a 4mm diameter cooper electrode and varied from 100 to 700 Amps. The deformation of the free surface just under the electrode is reported in term of depth. At some critical current an arc develops around the electrode tip. The results are interpreted with the help of a numerical model.

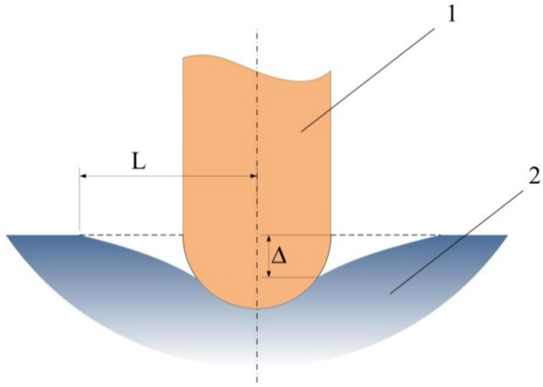
1.Introduction and numerical method

The present paper presents an investigation of an electrically induced flow[1,2] generated within a cylindrical container (Figure 1). Before the experiment the tip is fully immerged in the liquid metal(Galistan), once a current is applied the interface starts to deform. To understand the physical mechanisms involved in these experiments, simulations were performed with a 2D MHD-VOF numerical model. The spherically tipped electrode is dipped within the liquid metal so that the entire tip is entirely in contact with the liquid metal. The dimensions of the facilities are given in figure 1a. The current is applied from the top, and leaves from the bottom by traveling over a vertical wire strictly aligned with the electrode. The deformation of the interface (Fig. 1b, 2) is observed and measured optically with an optical camera. Before the application of the current, the electrode is carefully dipped within the liquid so that the half sphere electrode tip is fully immersed.

The numerical model assumes the system being laminar and 2D axisymmetric. The equations for electric potential, magnetic potential vectors, as well as the velocity field are solved in a fully coupled and transient way. The coupling between the flow and the electromagnetic field is done through the possible movement of the metal/air interface which can modify the electric current path. The fluid calculation domain is a hemisphere divided into 100 000 volume elements. The mesh is refined at vicinity of all wall boundaries, especially near the electrode so that the area of interest is correctly resolved. The electrode radius is 4 mm. The properties of the two phases are fixed [3] The electromagnetic domain includes the fluid domain and the electrode as well as the cooper container. The interface between the two phases is tracked with a geometric reconstruction VOF technique. A single set of momentum equations is shared by the fluids, and the volume fraction of each of the fluids in each computational cell is tracked throughout the domain. The electromagnetic field is solved by using the electric field ϕ and the magnetic potential vector $\vec{A}$. In the liquid the computed electromagnetic field is dynamically adjusted from the space distribution of the electric conductivity, which is in turn a function of the predicted phase distribution. The electric current and the induced magnetic field are fully coupled with the phase distribution. The influence of the axial component of the earth magnetic field is added to the magnetic field induced by the electric current. The motion of the metal and the air $\vec{U}$ is computed with the Navier-Stokes equations. More details about the numerical model used are given in [4]



(a)



(b)

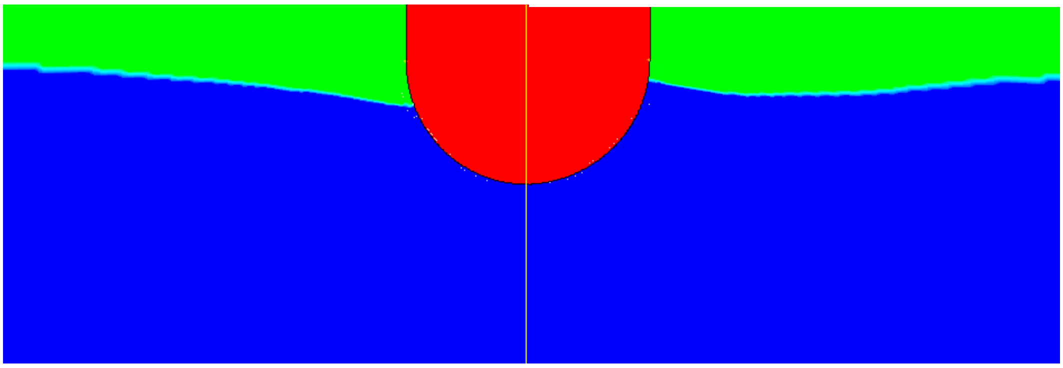
Figure 1: (a) dimension of the facility. **(b)** Scheme of surface deformation Δ – depth of cavern, L – width of cavern, 1 –electrode, 2 – liquid metal In-Ga-Sn.

Figure 2: Picture of the surface of the liquid metal. A plastic gain of pink colour surrounds the tip of the electrode. A dark area near the electrode appear when the cavern becomes deep and wide enough.

2. Results and discussion

A typical picture of the electrode region is shown in figure 2. An insulating gain of pink colour surrounds the tip of the electrode. This element is used a marker, the lower edge of tube is zero point. The distance between edge of tube and its reflection on the deformed surface of liquid metal (on photo) is measured. Notice the image reflexion produced by the clean metallic surface. Accuracy of the measurement is better than 0.05 mm. Qualitatively, the magnitude of surface deformation can be estimated by the extent of the dark region just under the electrode tip (Fig. 2). When the applied current exceeds a critical current an arc surrounding the electrode tip appears. The cavern depth increases with the applied current.

The position of the liquid metal surface at the electrode becomes invisible as soon as the arc appeared. Since the contact angle α of the free surface at the electrode is not known, simulations were performed with $I_0 = 350$ A for $\alpha = 120^o$ and 90^o(Fig.3). The case of $\alpha = 120^o$ gives the deepest cavern and the best fit with the experimental data(Fig. 4), this case will be presented and discussed in detail.



(a) 120^o (b) 90^o

Figure 3: Deformation of the interface predicted from simulations for electrode diameter 4 mm and for *I*=350 Amp. (Red : electrode, Green air, blue: liquid metal).

The resulting shape is determined by the balance between buoyancy, the surface tension, and the Lorenz forces. Due to the obtuse contact angle, the surface tension is oriented in the downward direction. Any further displacement of the interface must only be the result of the action of the electromagnetic forces. Assuming an equilibrium between buoyancy and the Lorentz force, we have : $\Delta \sim \alpha \frac{I^2}{\rho g}$, which is the main trend observed in figures 4. The factor α adds both the pinch and rotational effects of the Lorentz forces. A change in the increase rate is visible at around 100-200 Amps. This change in slope can be explained by the fact that for low applied current the pinch effect dominates, while at higher current the decrease of pressure due to the flow acceleration dominates.
The spherical shape of the electrode tip can lead to unstable configurations. As the electric current intensity is increased (I>275 A), the effective electrode radius (at the level of the interface) becomes smaller and smaller. Similarly the inclination of the electrode surface becomes less vertical and more horizontal. Equilibrium becomes difficult especially for the surface tension force which tries to keep the required contact angle. If the Lorentz force is not quickly balanced, either by buoyancy or by surface tension, the contact area will fluctuate. Amplitude of surface oscillations can be extracted by subtracting the maximum with the minimum depths reported in figure 4.

3. Conclusions

The deformation of a free surface by the application of an electric current has been experimentally and numerically studied. At low current density the interface is shifted downward by the pinch action of the Lorentz force. In the same time the rotational part of the Lorentz force drives the liquid metal flow in radial direction towards the electrode. The flow is accelerated towards the electrode and sinks in the form of a strong jet. At high current density, the velocities are strong enough to induce further displacement of the interface by a Bernoulli mechanism. The combined action of the pinch and the rotational components of the Lorentz force on the interface displacement, scales as I^2. The numerical and experimental results are in good agreements. Experimentally an arc develops around the electrode when the applied current exceeds a critical value. Just before the arc develops the electrode was still in good contact with the liquid metal. At the present stage it is not yet clear on whether the arc develops because of contact lost or because of the occurrence of an electric gas breakdown near the electrode surface.

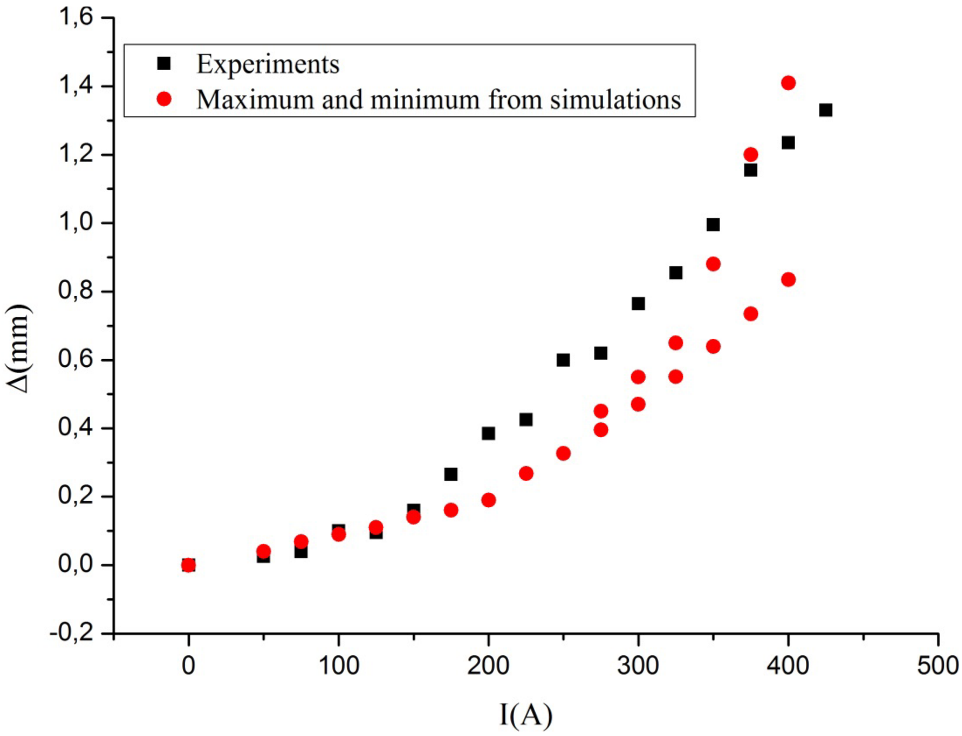


Figure 4: Predicted against experimentally observed cavern depths for the case of 4 mm electrode diameter. In the simulations the position of the interface is unstable for *I*>275 A.

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